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UNIT-4 (1)

LASERS

1) Distinguish between the ordinary and Laser light
2) Explain the processes of Spontaneous and Stimulated emission.
3) Distinguish between the Spontaneous and Stimulated emission.
4) what is a laser? Mention differences between ordinary light and laser light
5) Explain the processes involved in the interaction of radiation with matter.
6) With neat diagrams, Explain the terms: Induced absorption, Spontaneous emission and Stimulated emission.
7) Derive the expression for energy density of radiation under equilibrium condition in terms of Einstein coefficients, Arrive at the general form of the expression after comparing with Planck's equation.
8) write a note on requisites of laser System

   (OR)

   what are the basic components of a laser System? Explain the function of each Component.
9) Discuss the conditions for Laser action (OR) Explain the process involved in Laser action

   write a note on conditions required for Laser action

   (OR)

   Discuss the conditions for light amplification in lasers.
10) Explain the terms: population inversion, Metastable State active medium and laser Cavity
11) Describe the construction and working of a Semiconductor laser with diagrams. Mention its uses.
12) Describe the recording and reconstruction process in holography with the help of suitable diagrams. Mention its applications
13) Explain with Sketches the basic process involved in Lasers.

B

②

What is a Laser?

A laser is a device which produces high intensity of light of single wave length is called Laser.

The word LASER stands for 'Light amplification by Stimulated emission of radiation.

To understand the construction and working of a laser, it is necessary to know the basic processes involved in atomic systems.

Difference between Laser light and ordinary light :-

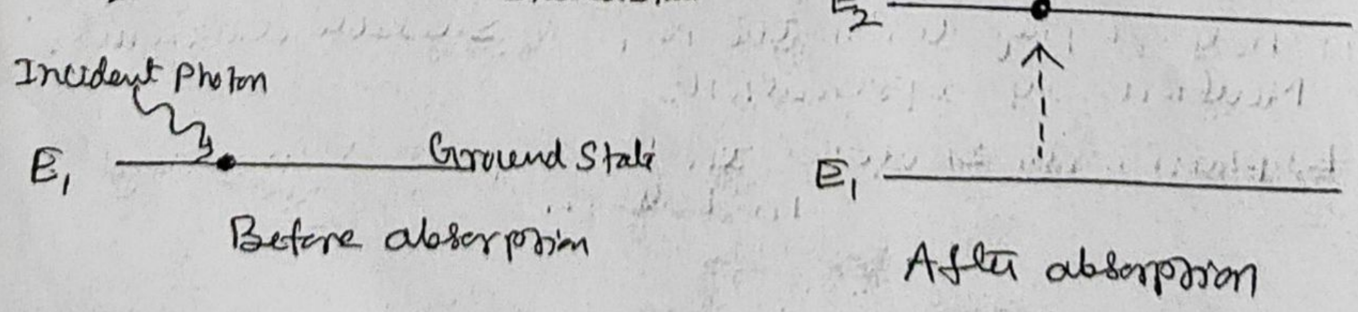
Laser light	ordinary light
1) Laser light is highly monochromatic	ordinary light is polychromatic
2) Laser light is highly coherent	ordinary light is incoherent
3) Laser light is highly directional	ordinary light is not directional
4) Intensity of laser light is high	Intensity of ordinary light is less
5) Laser light is narrow beam	ordinary light is a diverges beam

Interaction of radiation with matter :-

Radiation interact with atomic energy levels in three ways. They are

1) Induced absorption
2) Spontaneous emission
3) Stimulated emission

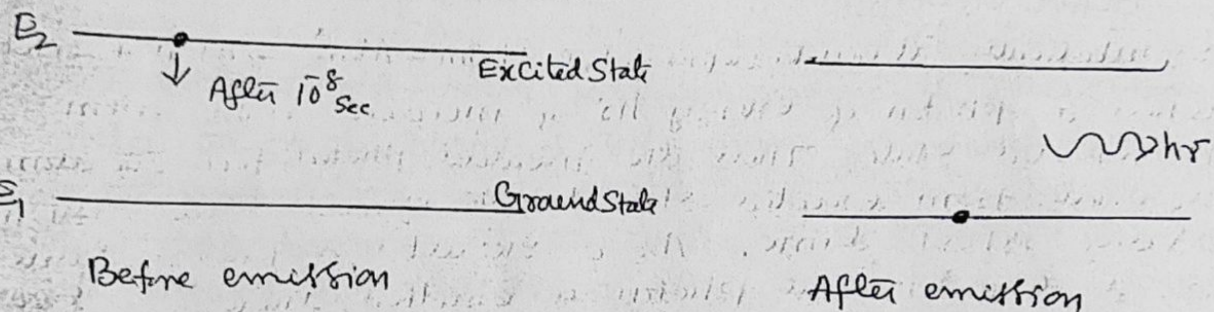
1) Induced absorption :-



Symbolically it can be represented as Photon + Atom $\rightarrow$ Atom*

When a photon is incident on the atom, this atom absorbes the energy of the incident photon and goes to the higher energy state. This process is called induced absorption. In this process, the photon vanishes and the atom is raised to higher state E_2.

② Spontaneous emission :-



Symbolically it can be represented as Atom* $\longrightarrow$ Atom + photon

If the atom initially in the upper state E_2 with in a short interval of time it can return to ground state E_1 by emitting a photon of energy $h\nu$. This process is called Spontaneous emission.

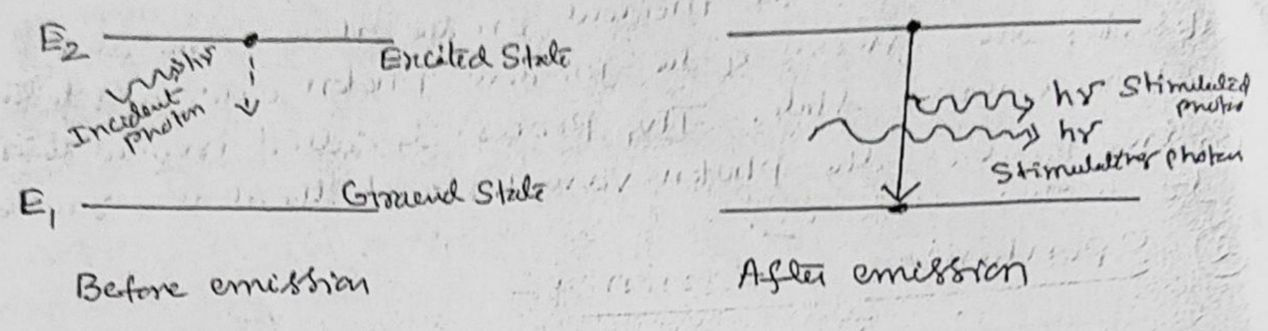
In this process the atom returns to the ground state and a photon is emitted. This emitted photons can move in any direction. Hence they are in coherent.

The light from sun, stars, electric bulb, sodium or mercury vapour lamp etc is generated by spontaneous emission.

(OR)

The emission of a photon by the excited atom without the aid of an external energy is called Spontaneous emission.

3) Stimulated emission :-



Symbolically, it can be represented as, Photon + Atom* → Atom + 2 photons

when a photon of energy hν is incident on the atom in excited state, Then the incident photon force the atom to move from excited state to the ground state with in a very short time. As a result, a photon, same as that of incident photon is emitted, there are two photons instead of one. This process is Known as Stimulated emission.

The emitted photons will have same velocity, direction and same phase as that of incident photon and they are coherent. This of the kind of emission is responsible for Laser action.

Stimulated emission is possible only if there are a large number of atoms in an excited state.

Ex:- Light from Laser Source.

(OR)

The process of emission of photons by an excited atom under the influence of an incident photon is called Stimulated emission.

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Difference between Spontaneous emission and Stimulated emission.

Spontaneous emission	Stimulated emission
1) $Atom^{*} \rightarrow Atom + photon$	$Photon + Atom^{*} \rightarrow Atom + 2\ photons$
2) it is independent of incident radiation density	it depends on the incident radiation density
3) incoherent radiation	Coherent radiation
4) Less intensity	high intensity

Production of Laser beam :-

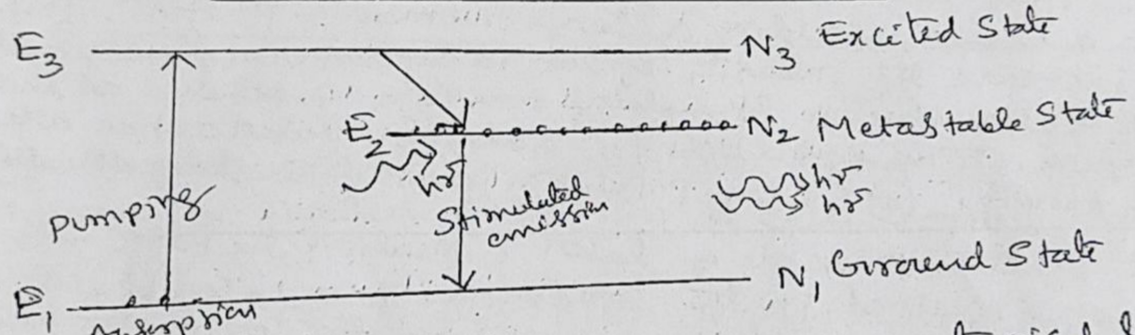
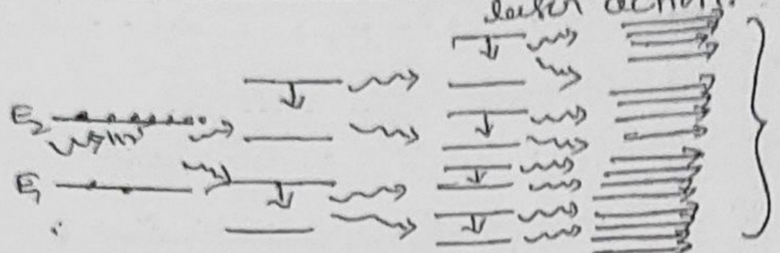


Figure shows the basic laser action of a typical laser. Consider all the atoms of the material are in the ground State. Then photon is incident on the atoms. The atoms in the ground State which absorb the energy and go to the excited State (E_3). Since the life time of each atom in the excited State E_3 is very Small. So all the atoms in the excited State E_3 Jump to the metastable State (E_2). The atoms in the metastable State can stay longer time (10^{-3} sec). Thus the population of atoms in the metastable State is more than the ground State. This situation is known as population inversion and the process of obtaining the P. I is known as pumping.

When excited atom Jump from metastable State to the ground State through Spontaneous emission, a photon is emitted. The photons are moving between two reflecting surfaces, Hence more and more Stimulated emission takes place. which results laser beam.

What is Laser action? Mention the conditions for laser action.



The action of laser is based on the principle of Stimulated emission. Consider a collection of atoms in the excited state. A photon of right energy may cause stimulated emission in one of these atoms resulting in two photons. These two photons are now incident on two other atoms in the excited state. Then we will get four photons. The process goes on in a chain, yielding a large number of photons. This will increase the intensity of the radiation enormously and amplification due to Stimulated emission is achieved as shown in figure. The conditions for obtaining laser action are as follows. (a) State of population inversion (b) Existence of a Metastable State.

What is the principle of laser? Mention the ~~basic atomic~~ concepts involved in the production of a Laser beam.

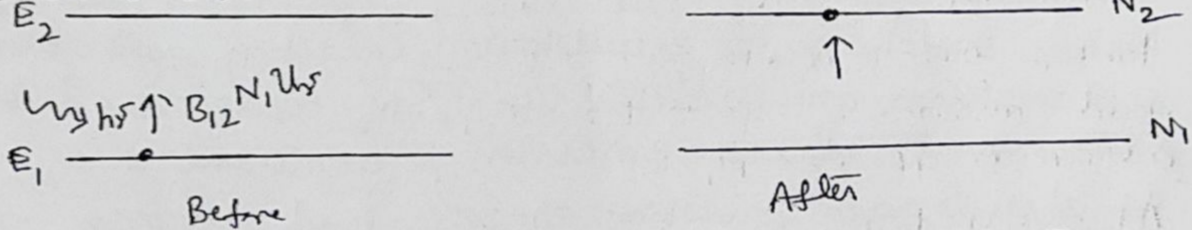
LASER is based on the principle that in the atomic systems possessing metastable state, the population inversion can be caused and then the process of Stimulated emission, can be used to produce Laser beam.

The basic concepts involved in the production of Laser beam are pumping, population inversion and the Stimulated emission.

Expression for energy density in terms of Einstein Coefficients :-

Consider two energy levels of an atomic system say E_1 and E_2 such that $E_2 > E_1$. Let N_1 and N_2 be the number of atoms in the energy levels E_1 and E_2 respectively. Let U_ν be the energy density of the incident radiation of frequency ν. When a radiation is incident on the atomic system following process occur simultaneously and the rates of these processes can be calculated as follows.

1) Induced absorption :-



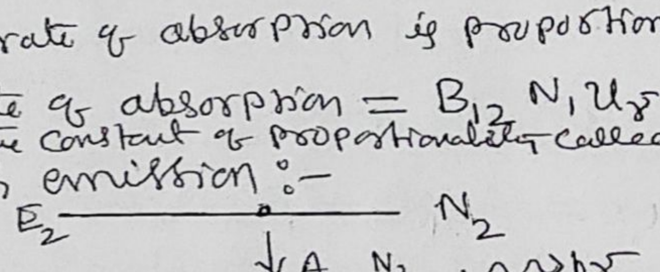
The number of atoms transition from E_1 to E_2 through a induced absorption is called rate of induced absorption.

Therefore The rate of absorption is proportional to $N_1 U_\nu$

The rate of absorption $= B_{12} N_1 U_\nu$ —— (1)

where B_{12} is the constant of proportionality called Einstein Coefficient

2) Spontaneous emission :-

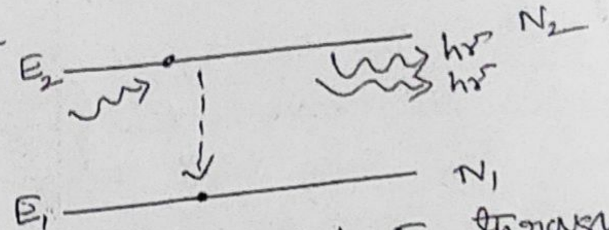


The number of atoms transition from E_2 to E_1 through a spontaneous emission is called rate of spontaneous emission. The rate of S. emission is directly proportional to N_2 and independent of energy density.

∴ The rate of spontaneous emission $= A_{21} N_2$ —— (2)

where A_{21} is a constant of proportionality called Einstein Coefficient

3) Stimulated emission :-



The number of atoms transition from E_2 to E_1 through a stimulated emission is called rate of stimulated emission. This rate is directly proportional to $N_2 U_\nu$

∴ The rate of Stimulated emission $= B_{21} N_2 U_\nu$ —③

where B_{21} is Einstein co-efficient.

Before reaching the equilibrium condition both absorption and emission are possible if $N_1 > N_2$ absorption is dominent. otherwise if $N_2 > N_1$ emission is dominent.

At equilibrium condition emission and absorption are equally possible.

At thermal equilibrium condition

Rate of absorption = Rate of emission

= Rate of Spontaneous emission + Rate of Stimulated emission

From equations ① ② and ③ we get

$$B_{12} N_1 U_\nu = A_{21} N_2 + B_{21} N_2 U_\nu$$

Re arranging the above relation we get

$$B_{12} N_1 U_\nu - B_{21} N_2 U_\nu = A_{21} N_2$$

$$U_\nu [B_{12} N_1 - B_{21} N_2] = A_{21} N_2$$

$$U_\nu = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2}$$

Dividing both the numerator and denominator by $B_{21} N_2$ Then

$$U_\nu = \frac{\frac{A_{21}}{B_{21}}}{\frac{B_{12} N_1}{B_{21} N_2} - 1} = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12} N_1}{B_{21} N_2} - 1} \right] \quad —④$$

The ratio of population of two energy state is given by the Boltzmann distribution law

$$\frac{N_2}{N_1} = e^{\frac{-(E_2-E_1)}{KT}} = e^{\frac{-h\nu}{KT}} \quad \therefore \frac{N_1}{N_2} = e^{\frac{h\nu}{KT}} \quad — (5)$$

Equation (4) becomes

$$U_\nu = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12}}{B_{21}} e^{\frac{h\nu}{KT}} - 1} \right] \quad — (6)$$

By the planck's radiation law

$$U_\nu = \frac{8\pi h\nu^3}{c^3} \left[\frac{1}{e^{\frac{h\nu}{KT}} - 1} \right] \quad — (7)$$

Comparing (6) and (7)

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \quad — (8) \quad \text{and} \quad \frac{B_{12}}{B_{21}} = 1 \quad \text{i.e } B_{12} = B_{21} \quad — (9)$$

Equation (8) and (9) first obtained by Einstein in 1917, Hence they are known as Einstein's relations.

The above equation implies that Induced absorption is equal to the Stimulated emission. Therefore A_{21} is written as A and B_{12}, B_{21} written as B.

Equation (6) Becoms

$$U_\nu = \frac{A}{B\left[e^{\frac{h\nu}{KT}} - 1\right]}$$

This is the expression for energy density in terms of Einstein Coefficients A and B.

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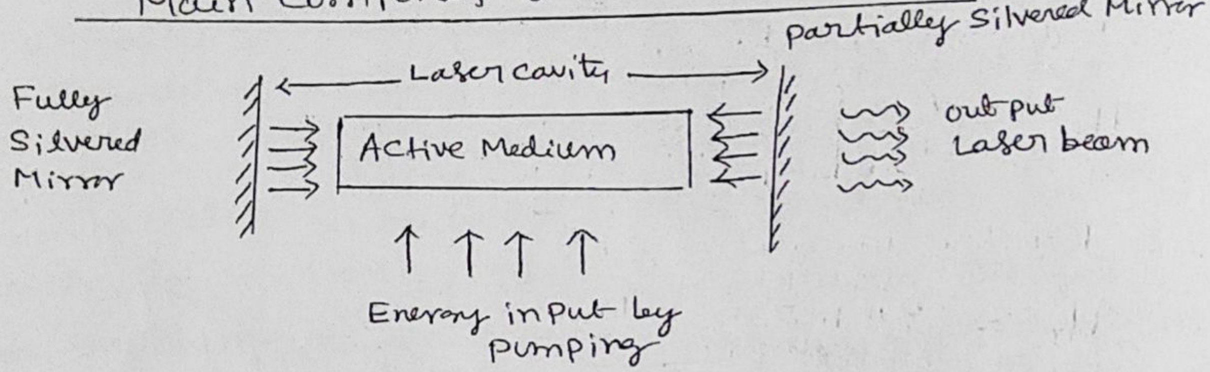
Requisites of a Laser System :-
(OR)
Requirements of a laser System :-
(OR)
Main components of a laser System :-



Basic Laser System

A Laser System Consists of three main components. They are

1) Pumping System (or) Energy Source (or) Excitation Source
2) An active medium
3) Optical resonator or Laser Cavity

1) Pumping System :-
This is Used to excite the atoms of active medium to higher energy levels. The energy input may be in different forms such as light, electron impact, electric current, Chemical reaction and heating etc.

2) An active medium :-
it is a medium which amplifies the light
The active medium may be Solid, liquid or gas
In the active medium Stimulated emission occurs
The active medium is kept between two plane mirrors.

3) Laser Cavity :-
it consists of two parallel mirrors, one of the mirror's is fully reflecting and the other is partially reflecting and it enclose the active medium. Hence the space between the two mirrors is known as the laser cavity. In which light (Photon)

oscillate back and forth between the mirrors. The photons with in the cavity undergoes multiple reflections between the mirrors. So that Stimulated emission is possible in more number of excited atoms. This naturally increses the intensity of the laser beam. Hence in the absence of cavity, there would be no generation of light.

In a Laser, the active medium does not produce required amplification in the light intensity. Hence to generate high intensity, the active medium is placed between the two mirrors. So it is called optical resonator.

Condition For Laser action :-

The process of emission of stimulated photon is called Laser action.

For the laser action, the following conditions are to be satisfied.

1) Population Inversion
2) Metastable State.

They are explained as follows.

1) Population Inversion :-

E_2 ——•••—— N_2

E_1 ••••••••••••••• N_1

Under normal condition

$$N_2 < N_1$$

At Room temperature ($T = 300K$) or under normal condition the number of atoms in the higher energy state is less than the number of atoms in the lower energy state.

E_2 ••••••••••••• N_2

E_1 ——•••—— N_1

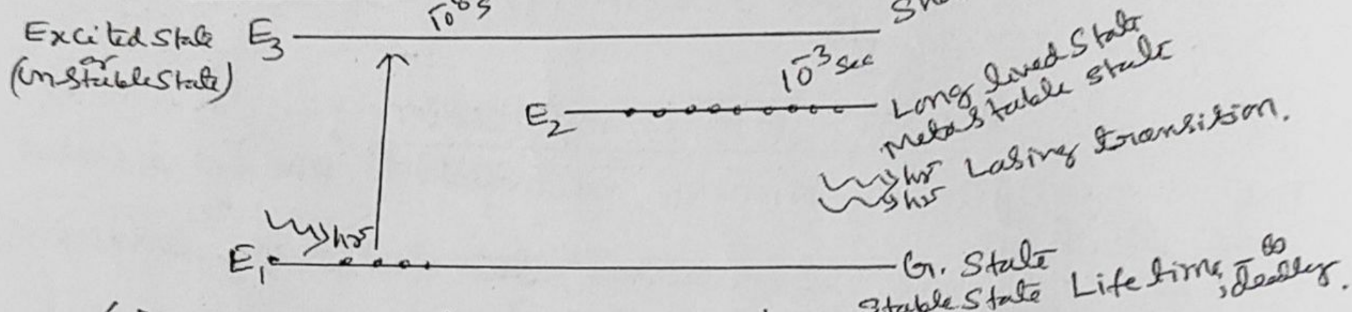
$$N_2 > N_1$$

Making $N_2 > N_1$ i.e The number of atoms in higher energy state is greater than that of the lower energy state is called as Population Inversion. Then if a P.I exists in an active medium, then stimulated emission takes place. Therefore P.I is an essential condition for producing laser action.

OR

The inversion of atoms is called Population Inversion i.e $N_2 > N_1$

② Meta Stable State:-



(If an atom has three energy levels)

The energy state in an atomic system, where the life time of an atom in that state is 10^{-3} sec. So it is called the metastable state.

OR

The atomic system which possess a special kind of excited state is called metastable state.

UNIT-4 LASER ③

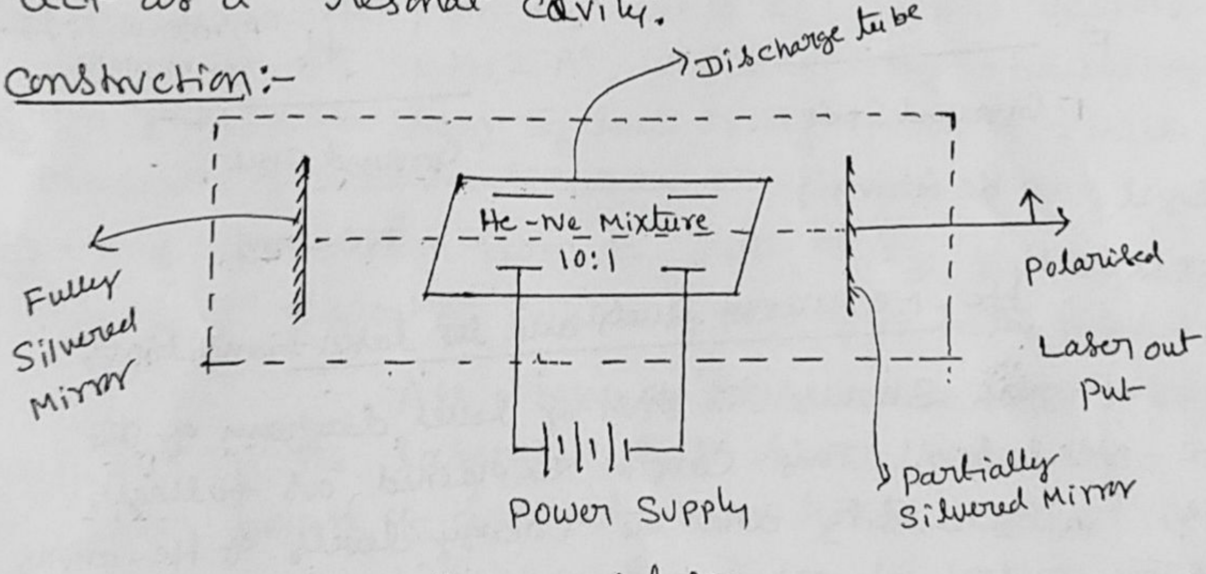
Helium - Neon gas LASER (OR) He-Ne gas laser

He-Ne laser was the first gas laser. This laser was invented by Javan, Bennett and Harriot in 1961

Principle:- it works on the principle of resonant energy exchange collision between excited Helium atom and ground state of. ~~N~~eon atoms.

The mixture of He-Ne is used as laser medium here Ne is an active medium. Helium atoms help in exciting neon atoms. The electric discharge method is employed for pumping action. Mirrors act as a resonat cavity.

Construction:-



He-Ne gas laser

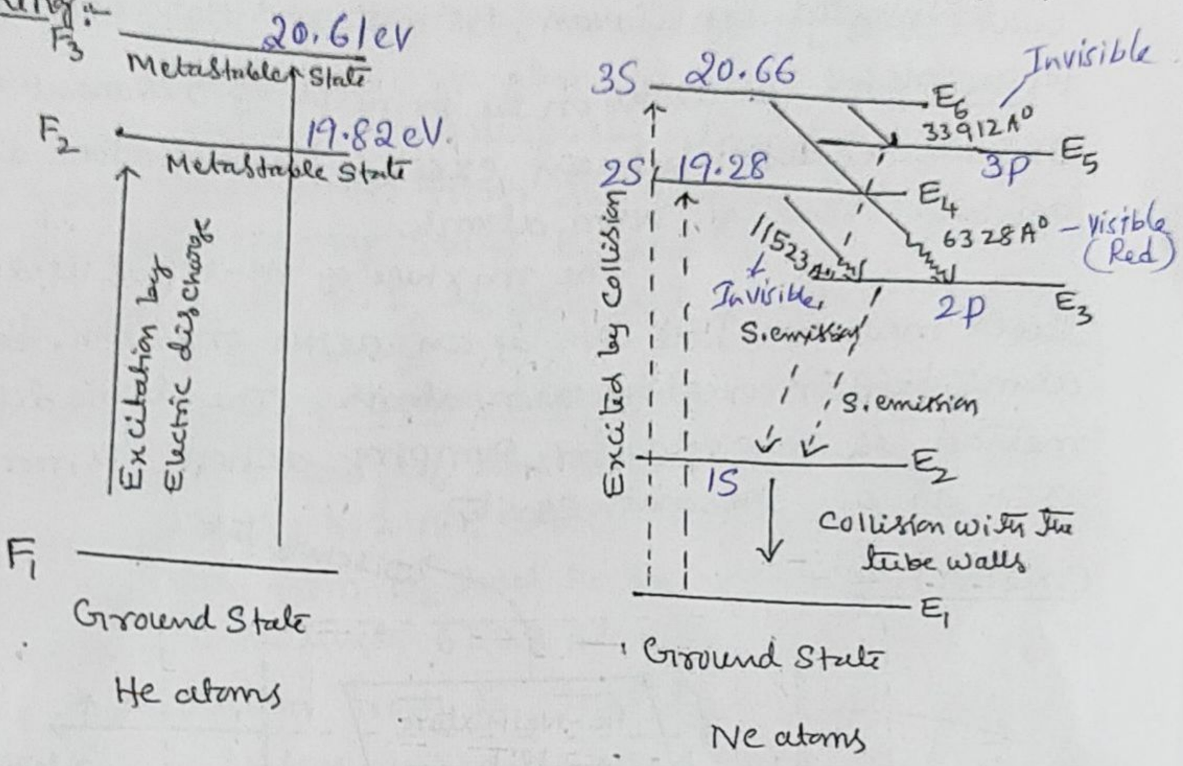
The construction of He-Ne laser is shown in figure, it consists of a long and narrow discharge tube of length 1m and diameter of about 1.5cm and which is filled with He-Ne gas mixture 10:1 ratio.

The pressure of Helium is about 10 times that of Ne. The electrodes are connected to power supply to create dicharge in the gas. The Mirrors are placed outside the tube as shown in figure.

The end of the tube are tilted at Brewster's angle as shown in figure. Therefore the

light emerges from the laser is linearly Polarised.
To understand the laser emission process, we require the energy levels of He and Ne which are illustrated in figure.

Working:-



He - Ne energy levels and the laser transitions

Figure shows the energy level diagram of the He-Ne laser. This can be explained as follows. The F_1 F_2 and F_3 are the energy levels of He-atoms. The E_1 E_2 E_3 E_4 E_5 and E_6 are the energy levels of Neon atoms.

When the power is switched on, a high voltage of about 1000 Volts is applied across the electrode. This is sufficient to ionize the gas. Then fast moving electrons are produced. These electrons collide with Helium and Neon atoms and excite them to higher energy levels F_2 and F_3. On the other hand energy states E_4 and E_6 of neon are equal to the energy states F_2 and F_3 of helium.

⑤

Because of this when helium atoms in the energy States F_2 and F_3 Collides with neon atoms in the ground State E_1, Then Ne atoms absorb energy and are excited to the energy States E_4 and E_6. After collision, the He atoms returns to ground State. This Process continuously tranfers more and more neon atoms from the ground State E_1 to the excited energy States E_4 and E_6.

Therefore, the P.I is achieved between E_6 and E_5, E_6 and E_3 and E_4 and E_3.

Now three types of Laser transition takes place.

(a) The Transition from E_6 level to E_5 produces radiation of wavelength 33912 A°, which is lying in fra-red region.

(b) The Transition from E_6 level to E_3 produces visible radiation of wave length 6328 A°. which is a red light.

(c) The Transition from E_4 level to E_3 give rise to 11523 A° radiation which is also lying in the infrared region

All three of these wavelength may be present in the laser out put simultaneously. A laser beam of desired wave length could be trapped by adjusting the distance between the two mirrors, while other radiations are suppressed. Hence the mirrors is called resonant cavity for the radiation.

The Ne atom then drop down to level E_2 through Spontaneous emission. These atoms then come down to the ground State by Collision with tube walls.

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(6)

The following energy transitions takes place

$F_1 \rightarrow F_3$ excitation — $He + e \rightarrow He^* + e$

$F_1 - F_2$ excitation — $He^* + Ne \rightarrow Ne^* + He$

$E_1 - E_6$ excitation

$E_1 - E_4$ excitation

3S→3P $E_6 - E_5$ Laser transition 33912 A°

3S→2P $E_6 - E_3$ Laser transition 6328 A°

2S→2P $E_4 - E_3$ Laser transition 11523 A°

$E_5 - E_2$ - Spontaneous emission

$E_3 - E_2$ Spontaneous emission

$E_2 - E_1$ collision with tube walls.

Advantages:—

i) The out put is continuous and low power

ii) it is inexpensive

iii) it is very Stable

iv) it requires less power consumption

Uses:—

i) it is used in laboratory experiments

ii) it is used in communications

iii) it is used in measurement of air pollution

iv) it is used in Scientific research.

L

① The average out put power of laser source emitting a laser beam of wave length 6328 A° is 5 mW. Find the number of photons emitted per second by the laser source.

$E = P \times t$ E = power × duration of time

$P = 5 mW$

$P = 5 \times 10^{-3} W$

$t = 1 Sec$

$\lambda = 6328 \times 10^{-10} m$

$h = 6.63 \times 10^{-34} J\text{-}S$

$c = 3 \times 10^{8} m/s$

$E = nh\nu = \frac{nhc}{\lambda}$

$Pt = \frac{nhc}{\lambda}$ $n = \frac{\lambda P t}{hc}$

$$n = \frac{6328 \times 10^{-10} \times 5 \times 10^{-3} \times 1}{6.63 \times 10^{-34} \times 3 \times 10^{8}} = 1.59 \times 10^{16} \text{ photons/sec}$$

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② A laser beam with power per pulse is 1.0 mW lasts 10 nS. If the number of photons emitted per pulse is 3.941×10^{7}. Calculate the wave length of laser.

$E = P \times t$ $E = \frac{nhc}{\lambda}$ $Pt = \frac{nhc}{\lambda}$

$$\lambda = \frac{nhc}{Pt} = \frac{3.941 \times 10^{7} \times 6.63 \times 10^{-34} \times 3 \times 10^{8}}{1 \times 10^{-3} \times 10 \times 10^{-9}} = 7839 A°$$

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③ A Laser medium at thermal equilibrium temperature 300 K has two energy levels with a wave length separation of 1 μm. Find the ratio of population densities of the upper and lower levels.

$h = 6.63 \times 10^{-34} J\text{-}S$

$c = 3 \times 10^{8} m/s$

$\lambda = 1 \times 10^{-6} m$

$K = 1.38 \times 10^{-23} J/K$

$T = 300 K$

$$\frac{N_2}{N_1} = e^{-\frac{(E_2 - E_1)}{KT}} = e^{\frac{-hc}{\lambda KT}}$$

$$\frac{N_2}{N_1} = e^{-\left(\frac{hc}{K}\right) \times \frac{1}{\lambda T}} = e^{\frac{-0.014413}{\lambda T}}$$

$$\frac{N_2}{N_1} = e^{\frac{-0.014413}{10^{-6} \times 300}} = e^{-48.043} = 1.365 \times 10^{-21}$$

④ Find the ratio of population of two energy levels in a laser if the transition between them produces light of wave length 694.3 nm. Assume the ambient temperature as 27°C.

$$\frac{N_2}{N_1} = e^{\frac{-(E_2-E_1)}{KT}} = e^{\frac{-hc}{\lambda KT}}$$

h =
e =
$\lambda = 694.3 \times 10^{-9} m$
$T = 27^0 c = 300 K$

$$\frac{N_2}{N_1} = e^{-\frac{6.63\times10^{-34}\times3\times10^{8}}{694.3\times10^{-9}\times1.38\times10^{-23}\times300}} = e^{-69.196}$$

$$\frac{N_2}{N_1} = 8.874 \times 10^{-31}$$

(5) The ratio of population of two energy levels is 1.059×10^{-30}. Find the wave length of light emitted at 300 K.

$\frac{N_2}{N_1} = 1.059 \times 10^{-30}$
$T = 300 K$
$\lambda = ?$

$$\frac{N_2}{N_1} = e^{\frac{-hc}{\lambda KT}}$$

Taking natural log on both sides

$$\ln \frac{N_2}{N_1} = -\frac{hc}{\lambda KT} \log(e) = -\left(\frac{hc}{K}\right) \times \frac{1}{\lambda T} \times \log(e)$$

$$\ln \frac{N_2}{N_1} = \frac{-0.014413}{\lambda T}$$

$$\lambda = \frac{-0.014413}{\ln\left(\frac{N_2}{N_1}\right) \times T} = \frac{-0.014413}{\ln(1.059\times10^{-30}) \times 300} = 696\,nm$$